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# Basic Cost Risk Analysis

*How to evaluate cost risk and  
uncertainty in your estimate*

# Acknowledgments

- This module was developed by Booz Allen Hamilton
- SCEA is indebted to TASC, Inc. for the development and maintenance of the Cost Estimating Body of Knowledge (CEBoK)
- SCEA is also indebted to the following individuals who have made significant contributions to the development, review, and maintenance of CostPROF and CEBoK
- Module 9 Cost and Schedule Risk Analysis
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- Basic Categories of Risk
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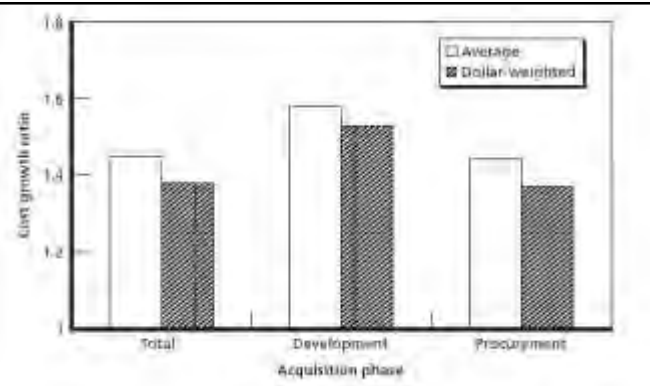
# Introduction to Risk

- Historical Cost Growth Patterns
- Introduction
- Definitions
- Uses
- S-Curves

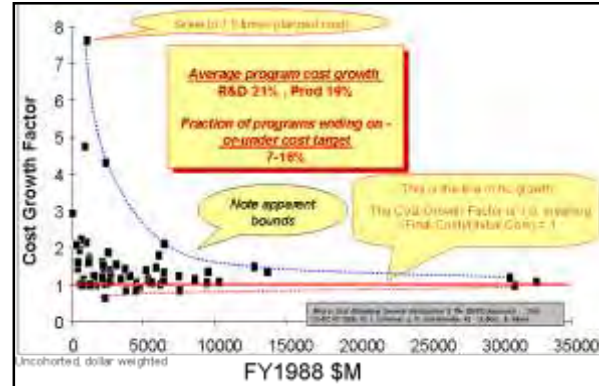
# What is the Problem

## Why Do We Need Cost Risk Analysis?

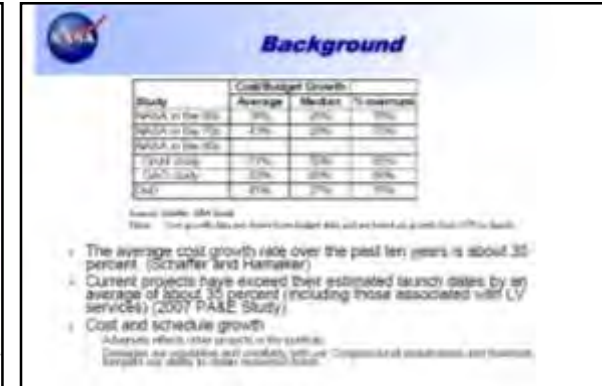
- Numerous studies have shown on average, government programs experience significant cost growth
  - RAND - 43% Average Cost Growth
  - BMDO - 21% R&D, 19% Production Cost Growth
  - NASA in the 90s - 36% Average Cost Growth



Is Weapon System Cost Growth Increasing. A quantitative Assessment of Completed and Ongoing Programs. RAND Project Air Force, 2007



Risk is Cost Estimating, General introduction & the BMDO Approach to Risk. Coleman, Summerville, DuBois, Myers. DoDCAS. 2000.



Cost Estimating Requirements to Support New Congressional Reporting Requirements. Coonce, Rutkowski, Hunt. NASA PM Challenge, 2008.

# What is the Problem

## *Why Do We Need Cost Risk Analysis?*

- Risk Analysis techniques are used to develop a range of potential final costs to assist decision makers in formulating budgets and managing their programs
  - A point estimate by itself is just that - one possible outcome
  - Probabilistic cost estimates produced during risk analysis allow decision makers to budget programs with statistical confidence
- For major system acquisitions it is a requirement that risk and uncertainty be considered in cost estimates
  - DoD 5000.4-M
  - Clinger-Cohen Act
  - Air Force Policy Directives

# Introduction

- Risk analysis is as broad a topic as cost analysis and this module does not cover every topic, nor could it
- Risk analysis is thought of as separate effort from cost estimating
- To be effective, cost estimating & risk must be fully integrated
  - Impact of schedule and technical risks should be quantified by the cost estimators
  - For all parametric estimates, cost uncertainty is included in CER stats
  - Correlation between cost elements should be captured and quantified
- Risk analysis is the combination of several disciplines which makes it difficult to create subject matter experts
  - Math
  - Economics
  - Computer Science
  - Engineering
  - Software
  - Acquisition

***For any input or method utilized in your estimate you should think about the associated uncertainty***



# Definitions

- Risk analysis terms are used in many different fields, but often with different meanings - The following definitions will create a terminology specific to risk analysis
- Risk in Finance
  - Risk is the variability of returns from an investment<sup>1</sup>
  - In finance, risk refers to variance
- Risk in Cost
  - The probability of loss due to cost overrun
  - In cost, risk refers to the mean
  - Variance is described as uncertainty

<sup>1</sup> Wall Street Words: An A to Z Guide to Investment Terms for Today's Investor. Scott, David. 1993

<sup>2</sup> BusinessDictionary.com

# Risk vs. Uncertainty

- Terms are used somewhat interchangeably
- Cost Risk
  - The difference between the point estimate or target cost and any desired metric from the probabilistic cost estimate
  - Example: How many more dollars should I budget above my Point Estimate to have 80% confidence in program execution?
- Cost Uncertainty
  - Variance of the probabilistic cost estimate
  - Variance in CERs, technical parameters, rates, schedule, etc.
    - Examples: 1-2 FTEs, 10 lbs +/- 2, 80 months w/  $\sigma$ 10 months,
    - The standard deviation is generally used as the metric to describe uncertainty

# Definitions

- Risk Management
  - Policies, procedures and practices involved in the identification, analysis, assessment, control and avoidance, minimization, or elimination of unacceptable risks<sup>1</sup>
- Risk Analysis
  - Technique used to quantify the impact of uncertainty
- Risk analysis and risk management should occur side by side
  - Schedule, technical and programmatic risks uncovered during the risk management phase are quantified and accounted for in the risk adjusted cost estimate
  - Identified risks should be carried through the program's lifecycle and the estimate amended as appropriate

<sup>1</sup> BusinessDictionary.com

# Uses of Risk Analysis

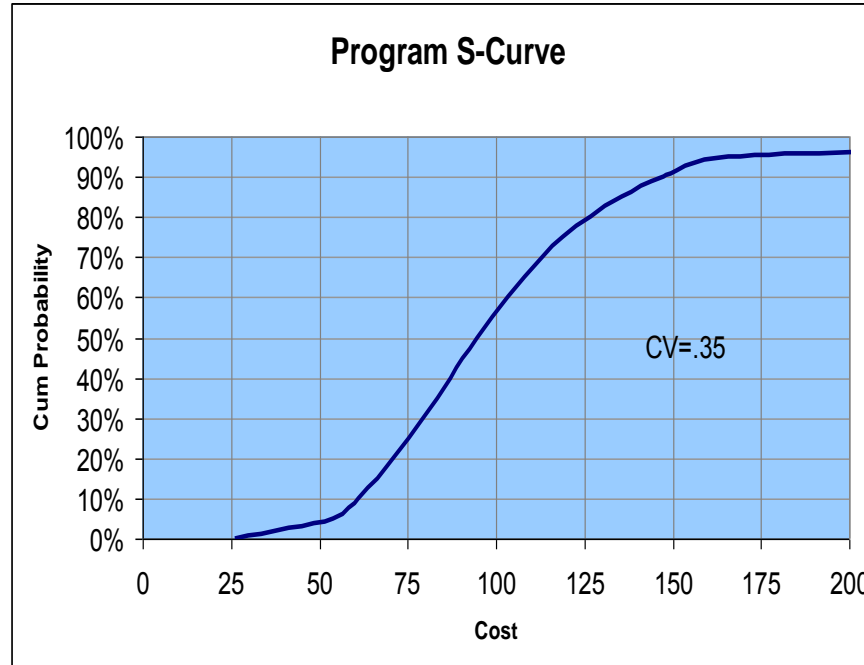
- Risk analysis is conducted to determine the potential range of costs for a program
- It is performed by all of the program's stakeholders
  - Contractor
    - Determine bid positions
    - Aid in negotiations
    - Determine management reserve levels
  - Program office
    - Develop budgets
    - Produce risk mitigation plans
    - Determine reserve levels
  - Cost oversight agency
    - Develop an independent assessment of potential costs
    - Determine confidence level of program office or contractor estimate

# More Uses

- Cost Risk analysis used to address the following questions:
  - What is the range of potential costs for this program?
  - In order to be confident there will be minimal cost overrun, at what level do I need to fund this program?
  - Given the risks and uncertainty surrounding my cost estimate, how do I spread risk dollars within my WBS?
  - How much reserve (or holdback) should I allocate for this program?
  - What is my optimal risk mitigation strategy? What are the cost impacts of these risks?
  - Given a set of alternatives, what is my optimal solution?
- S-Curves are used to answer these questions

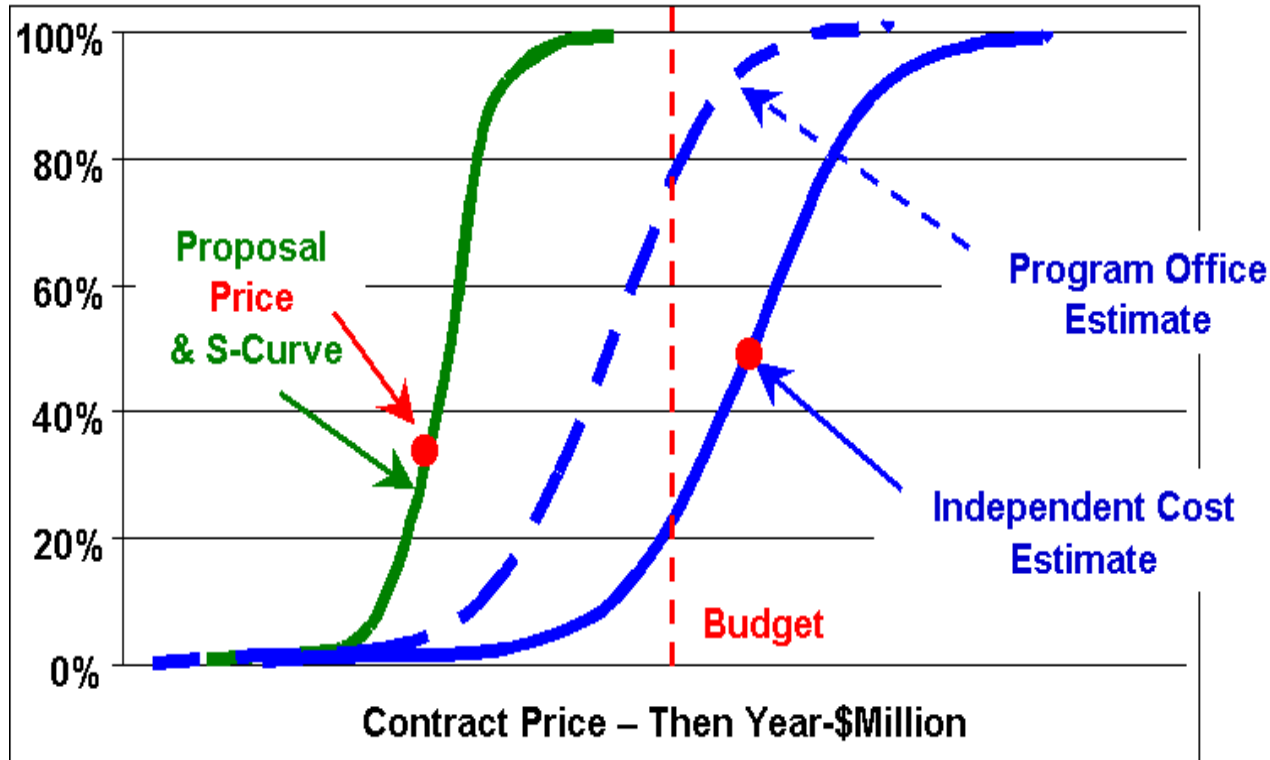
# S-Curves

## (Cumulative Distribution Function)



- The S-Curve (or probabilistic cost estimate) is a key piece of information and should be generated for every cost risk analysis
- It has a direct impact on formation of budget numbers
- For each point  $[x, F(x)]$ 
  - $F(x)$  = probability that the final outcome is  $\leq x$
  - Or, for costs, the probability that the final cost of a program is  $\leq x$

# S-Curves



- What information does these probabilistic cost estimates provide about program X?

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# Performing Risk Analysis

- Risk Analysis Methodologies
- Risk Analysis Process



# Risk Analysis Methodologies

- As you complete your risk analysis, you may utilize different methods for individual WBS elements
- Inputs-Based Simulation ([SWBS 100 Example](#))
  - A simulation is used where risk and uncertainty are applied to cost drivers and the estimates they generate
- Outputs-Based Simulation
  - Historically derived risk and uncertainty distributions are applied directly to costs
- Risk Cube Method
  - Risks and opportunities included in the risk management effort are applied to the cost estimate
- Scenario-Based Method
  - An analytical approach that produces a risk-adjusted cost estimate based on a set of conditions a program manager wants to consider

# General Risk Analysis Steps

1. Develop point estimate ✓
2. Identify the risk areas in the point estimate
3. Determine uncertainty around point estimate
4. Apply correlation between uncertainty distributions
5. Run the simulation
6. Assess the reasonableness of results/check for errors
7. Calculate, allocate and phase risk dollars (if applicable)
8. Tell the risk story - show the results

# Types of Risk

- **Cost Estimating Risk:** Risk due to cost estimating errors, and the statistical uncertainty in the estimate
- **Schedule/Technical Risk:** Risk due to the difficulty of conquering problems posed by the intended design in the current CARD or System Specifications
- **Requirements Risk:** Risk resulting from an as-yet-unseen design shift from the current CARD or System Specifications arising due to shortfalls in the documents
  - Due to the inability of the intended design to perform the (unchanged) intended mission
  - “Our solution didn’t address the requirements”
  - This category of risk is difficult to assess but is critical in order to have a comprehensive risk assessment
- **Threat Risk:** Risk due to an unrevealed threat; e.g. shift from the current STAR or threat assessment - The problem changed

Often implicit or omitted

# General Risk Analysis Steps

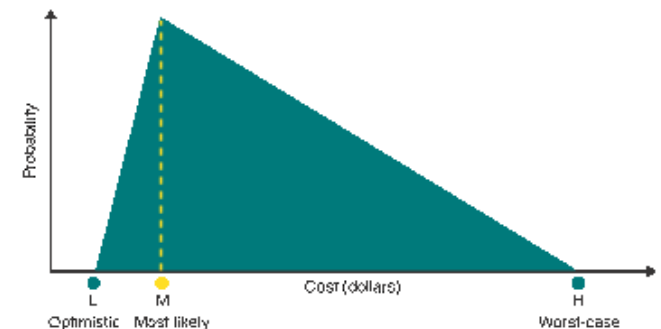
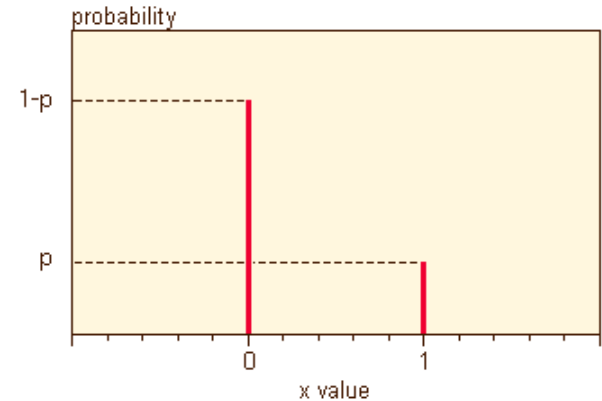
1. Develop point estimate ✓
2. Identify the risk areas in the point estimate ✓
3. Determine uncertainty around point estimate
  - Review of Risk Distributions
  - Statistical Methods
  - Subjective Methods
4. Apply correlation between uncertainty distributions
5. Run the simulation
6. Assess the reasonableness of results/check for errors
7. Calculate, allocate and phase risk dollars (if applicable)
8. Tell the risk story - show the results

# Selecting Risk Distributions

- Choice of risk distributions has the single largest effect on the analysis
- The method used to select these distributions should be based on available data
- In general, three methods for choosing risk distributions (in order of preference) are:
  1. Math: All parametric methods have a mathematical way of determining the risk distribution around the estimate
  2. Data: If needed, fit a distribution to the data using a tool such as Crystal Ball
  3. Subjective Inputs: As a last resort, conduct SME interviews to determine the risk distribution
    - Be sure to consider adjusting the SME developed parameters

# Review of Risk Distributions

- Bernoulli – Discrete/Single Outcome
  - Used for risks that either occur, or don't
  - Inputs:
    - Pf: Probability of occurrence
    - Cf: Cost impact if risk occurs
  - Expected Value =  $Pf * Cf$
- Triangular - Continuous/Range of Consequences
  - Uses the minimum/mode/maximum cost impact to create a continuous distribution
  - Inputs:
    - Minimum cost impact if risk occurs
    - Mode of cost impact if risk occurs
    - Maximum cost impact if risk occurs
  - Expected Value =  $(Min + Mode + Max) / 3$



# Review of Risk Distributions

- Beta

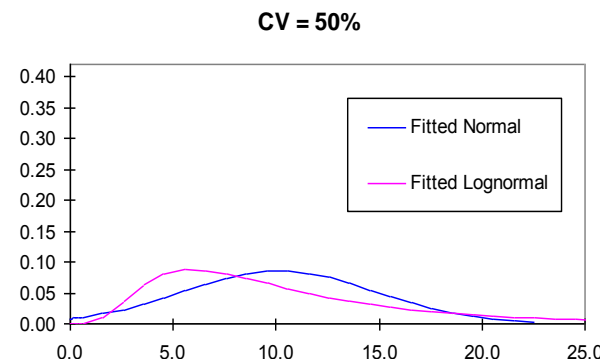
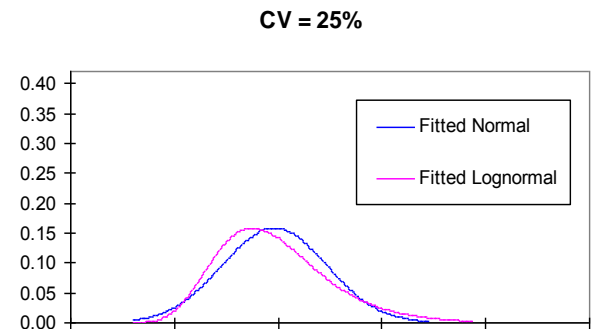
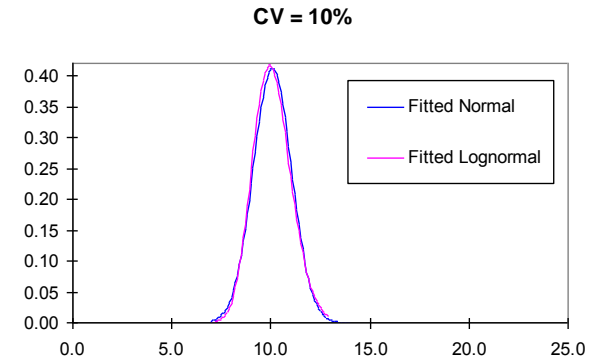
- Solves negative cost and duration issues
- Many parameters – simplifications like PERT Beta are possible
- Skewed

- Normal – Continuous/Range of Consequences

- Uses a mean and standard deviation to create a symmetrical continuous distribution
- Inputs: Mean, Standard Deviation
- Expected Value = Mean

- Lognormal – Continuous/Range of Consequences

- Uses a mean and standard deviation to create a skewed continuous distribution
- Inputs: Mean of Log, Standard Deviation of Log
- Expected Value:  $e^{\mu + \frac{\sigma^2}{2}}$



# Uncertainty Around the Point Estimate

The general steps for statistically assessing uncertainty around the point estimate are:

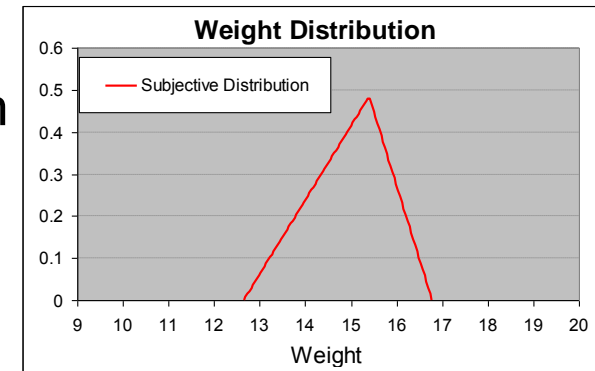
1. Assess uncertainty around the cost drivers (indep variables)
  - conduct interviews
  - study historical data, etc.
2. Assess uncertainty around the Cost Estimating Methodology
  - Almost every type of parametric analysis has an associated method of assessing uncertainty
3. Model the two together in a simulation

The following slides walk through process of estimating uncertainty



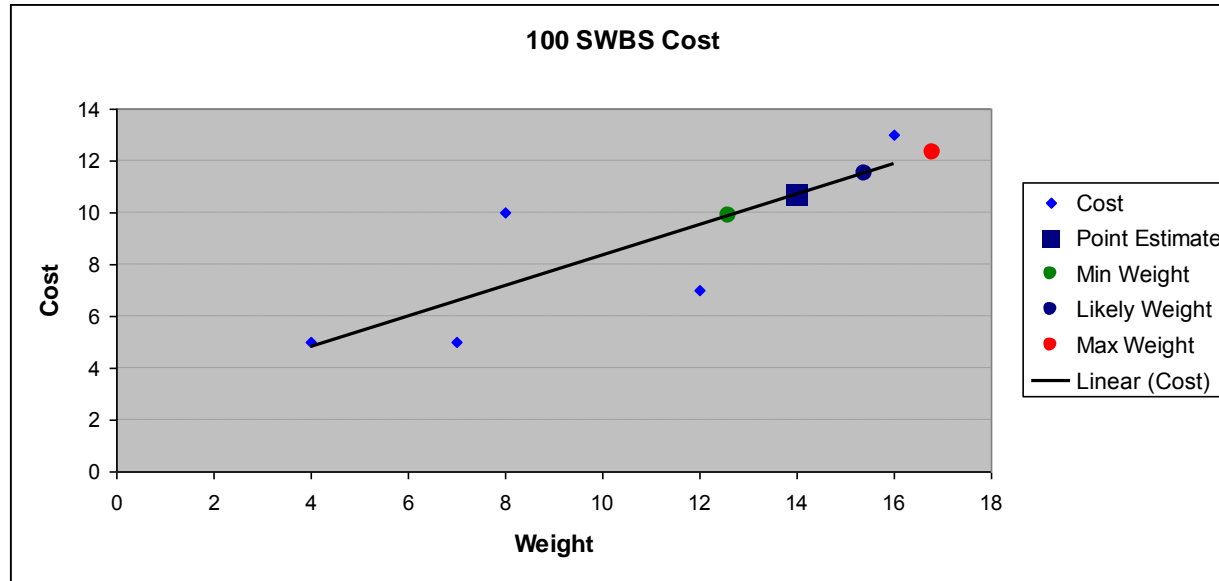
# Step 1: Assess Uncertainty around Cost Drivers

- Program Office has provided a weight estimate of 14 lbs
- After talking with program engineers it is discovered that the 14 lbs includes no contingency and the most likely weight is 15.4 lbs (requirements risk)
- A search of NAVY data reveals no historical weight growth distribution (statistical uncertainty)
- Instead, several engineers are interviewed. They state that the minimum weight is 12.6 lbs and the maximum weight is 16.8 lbs (subjective uncertainty)
- Uncertainty modeled as triangular distribution



***Always try the statistical approach first and validate with Program Engineer input***

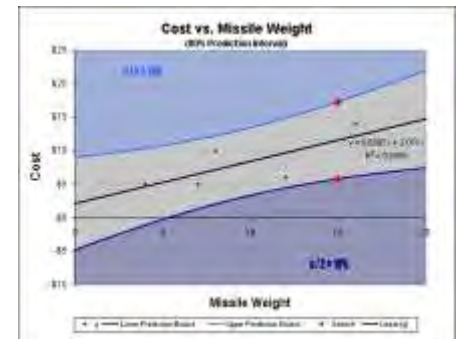
# Step 2: Assess the Uncertainty in Cost Estimating Methodology



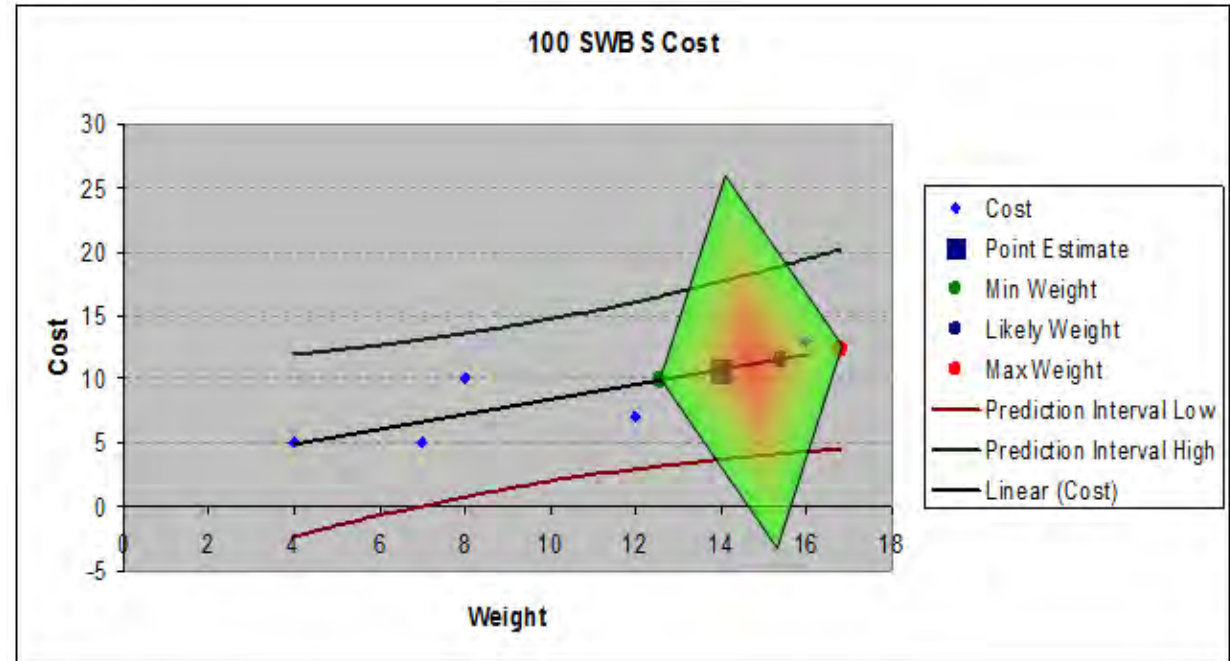
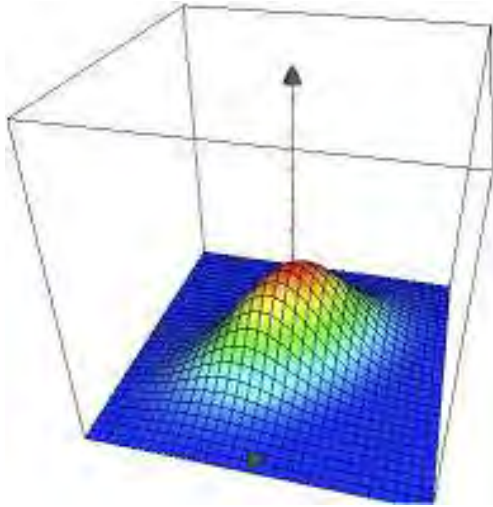
- The above CER is used to estimate the hull (SWBS 100)
- Point estimate at 14 pounds is \$10.69
- If only weight uncertainty was included in the estimate it would range from \$9.9 to \$12.3 - that's not all the uncertainty

# Prediction Interval Risk Distributions

- Accurate way to assess the uncertainty around the CER is to find the prediction interval around the CER and convert it into a risk distribution
- Oft misused measures of uncertainty:
  - Standard error of the estimate (SEE)
    - This is the error of the data points around the regression line, not the error of an estimate made using the regression
  - Normal distribution
    - Unless there are >30 data points, uncertainty should generally modeled with a fat-tailed distribution (such as a student's t-distribution)
- Correctly estimating uncertainty addresses common complaints
  - Estimating outside the range of data
    - PI's get wider as estimates are made further from the mean of the data
  - Estimating with few data points
    - PI's get wider the fewer data points are present

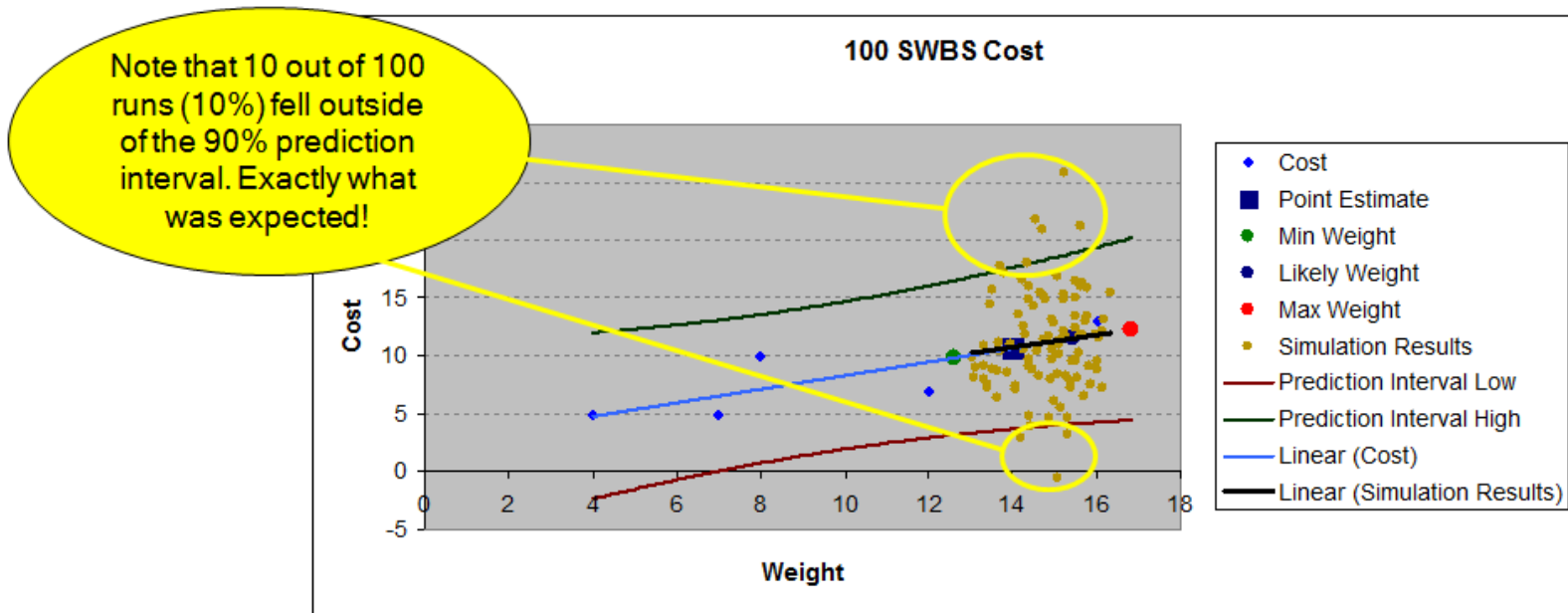


# Step 3: Simulation Model of Uncertainty



- The above graphs visualize the distribution of the cost estimate
- The distribution represents two uncertainties
  - Uncertainty in the weight estimate
  - Uncertainty in the CER-based estimate
- The distribution will be centered around the average weight and the cost estimate associated with it

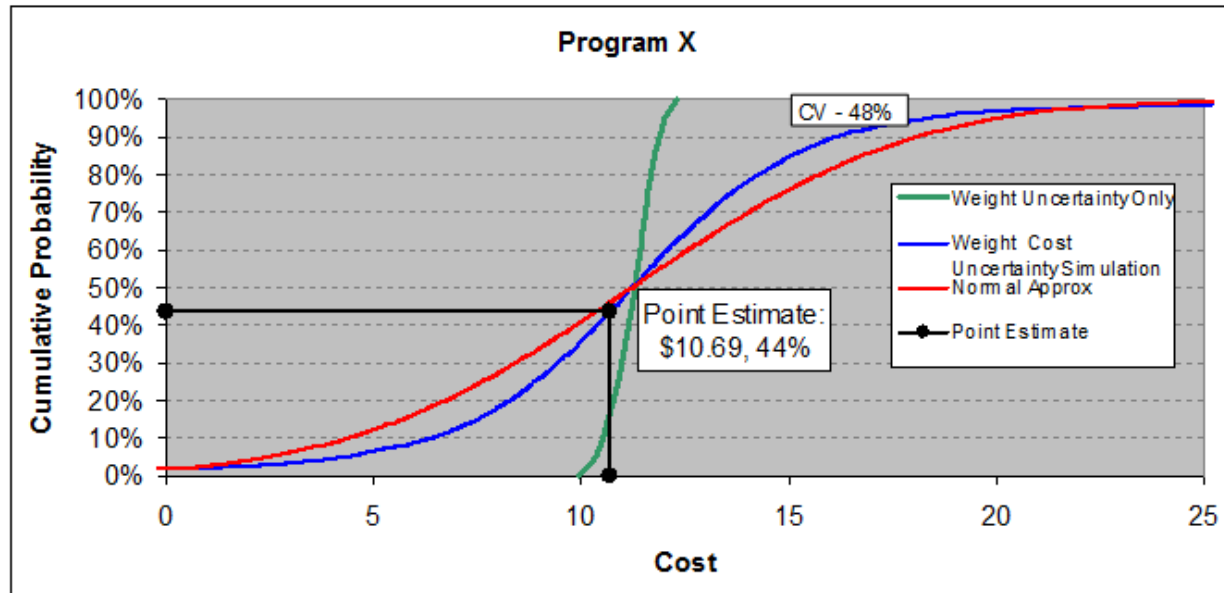
# The Simulation



- The final step is to model the uncertainty in a simulation
  - The simulation should be run to sanity check results, but will not be complete until risks, opportunities and correlation are added
- Example represents 100 runs of a simulation that models both of the aforementioned uncertainties
- Notice that the trend-line fitting the simulation points is almost exactly the same as the trend-line from the data points

# Example Results

	Min	20th	50th	Average	80th	Max
Weight	12.65	14.17	15.07	14.96	15.73	16.78
Cost	\$ (91.61)	\$ 8.29	\$ 11.21	\$ 11.21	\$ 14.26	\$ 75.29



- Once weight growth, weight uncertainty, and cost uncertainty are simulated, confidence in the Point estimate decreases to 44%
- Note that risk is not normally distributed in this case
  - Approximating estimating uncertainty as a normal distribution when there are <30 data points will provide a different answer

# Conclusion

- Capturing estimating uncertainty is generally the most difficult and time consuming portion of any risk analysis effort
- It is highly recommended that this step be combined with the cost estimating effort
  - For parametric estimates, uncertainty follows directly from the statistics
  - When subjective bounds are used it is useful to have the information used in the estimate close by for reference
- The benefits of risk analysis are plentiful
  - Provides cost analysts with a better technical understanding of the program and cost methodology
  - Increases the credibility of the cost estimate
  - Helps Program Managers make informed budget decision and manage risk
- Once uncertainty has been captured, it is time to account for discrete risks and opportunities

***Hopefully you have already started thinking about ways you can apply these techniques to your current estimate***

# Discrete Risks & Opportunities

- These are events that, if they occur, will impact cost and/or schedule
- This step should be integrated with the risk management effort
  - Risks collected by the risk management team should be incorporated into the risk analysis
  - These risks should be tracked throughout the lifetime of the program and used to update the program estimate
  - Results from the risk analysis should be used to aid in the choosing of risk mitigation plans
- Oftentimes, once the estimate is complete, risks and opportunities are forgotten until next estimate revision
  - Risks and opportunities uncovered within the risk analysis should be incorporated with the risk management effort

Adapted from: *Making Risk Management Tools More Credible: Calibrating the Risk Cube*. Coleman, Richard; Summerville, Jessica; Dameron, Megan. SCEA Conference. June 2006. Washington DC

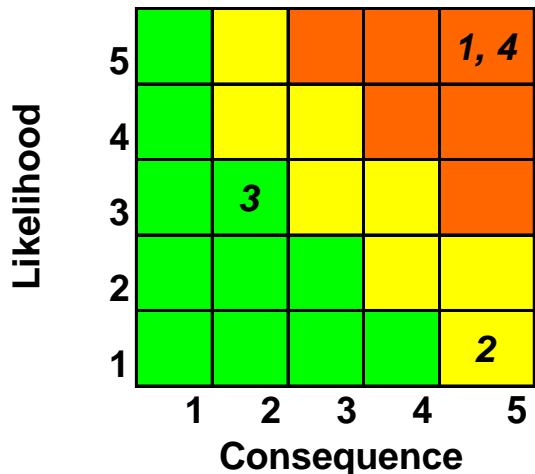


# Collecting Risks & Opportunities

- Risks & Opportunities are generally collected through interviews with engineers and the program management team
- When interviewing, try evoking risks using an if-then statement
  - Example: If the instrument doesn't pass environmental testing then a hardware re-spin will be required
- Beware of double counting when capturing risks and opportunities
  - Risks typical to similar programs are contained in the data used to generate the CERs or technology uncertainties (e.g. weight growth)
  - To avoid double counting try to focus on risks that are specific to the program that is the subject of the risk analysis

# Convert Risk Scoring to Pf and Cf

- The next step is to determine quantitative measures for Likelihood and Consequence
- Probability is somewhat easier to define than consequence (i.e. 0% Pf to 100% Pf)
- Consequence levels may take on different meanings when scoring

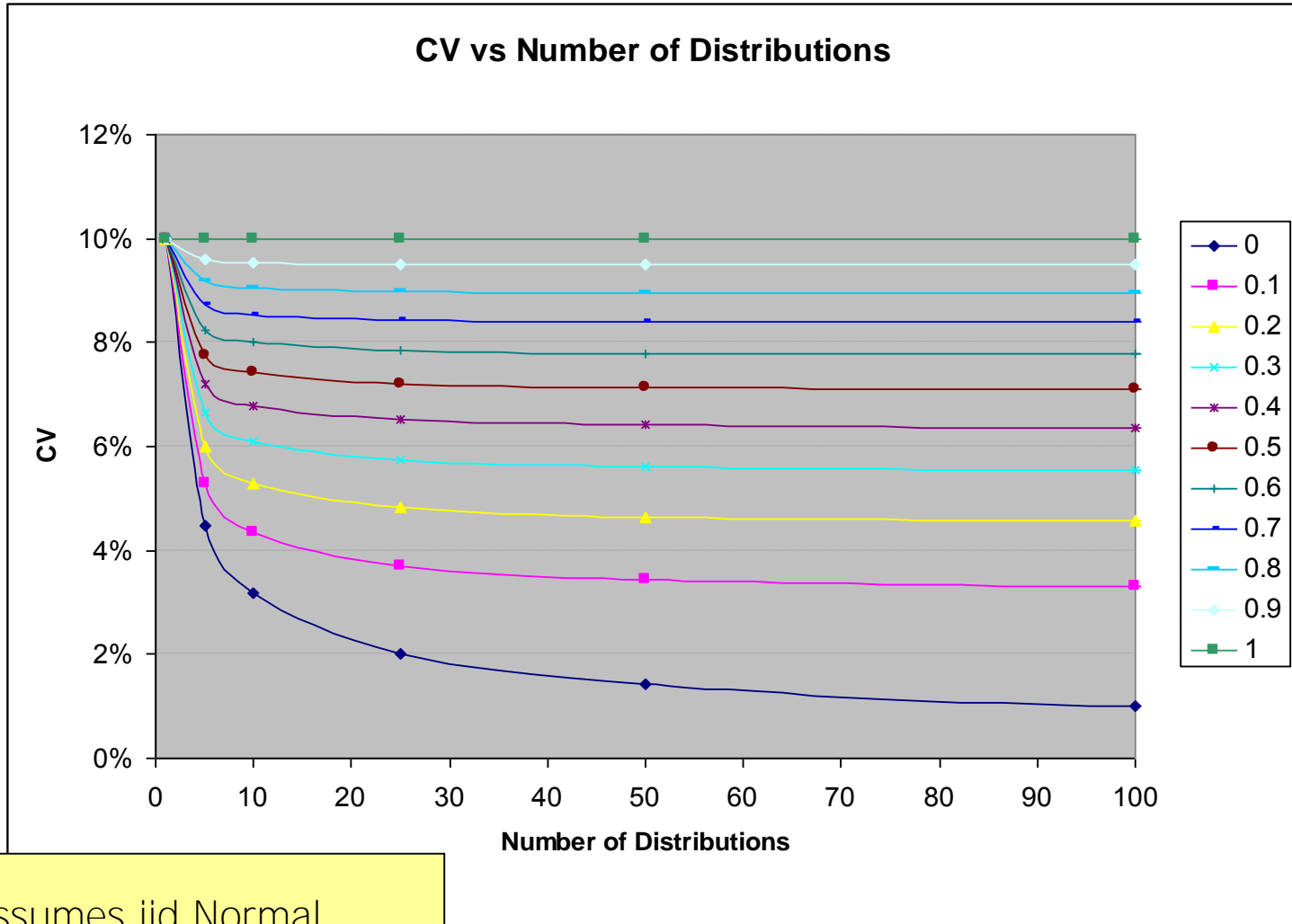


Level	Probability (Pf)	Definition
1	0.0 < Pf ≤ 0.2	Low likelihood
2	0.2 < Pf ≤ 0.4	Low-to-medium likelihood
3	0.4 < Pf ≤ 0.6	Medium
4	0.6 < Pf ≤ 0.8	Medium-to-high likelihood
5	0.8 < Pf ≤ 1.0	High likelihood

# Next Step

1. Develop point estimate ✓
2. Identify the risk areas in the point estimate ✓
3. Determine uncertainty around point estimate ✓
4. Apply correlation between uncertainty distributions
5. Run the simulation
6. Assess the reasonableness of results/check for errors
7. Calculate, allocate and phase risk dollars (if applicable)
8. Tell the risk story - show the results

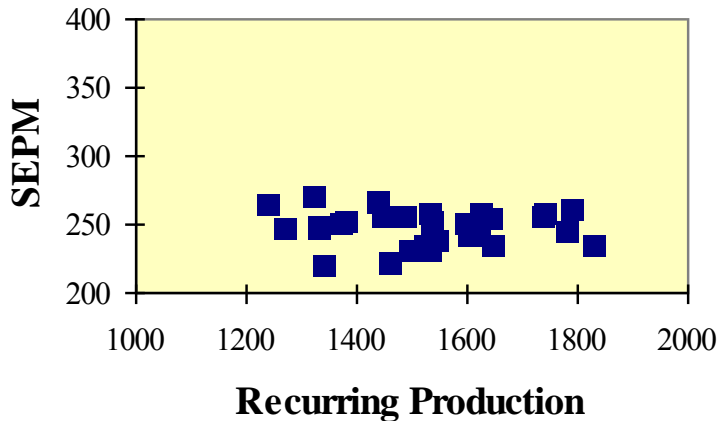
# “Square Root of N Problem”



Assumes iid Normal  
Distributions w/ CV of 10%

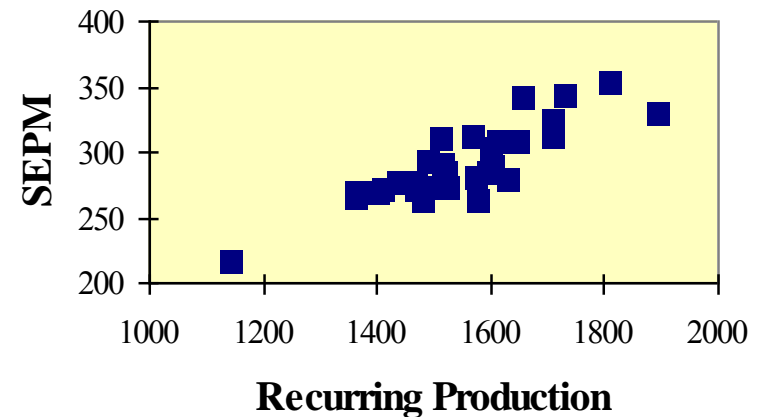
# Functional Correlation

- **Old:** No Functional Correlation; Simulation run with WBS items entered as values



Not Correlated

- **New:** Simulation run with functional dependencies entered as they are in cost model

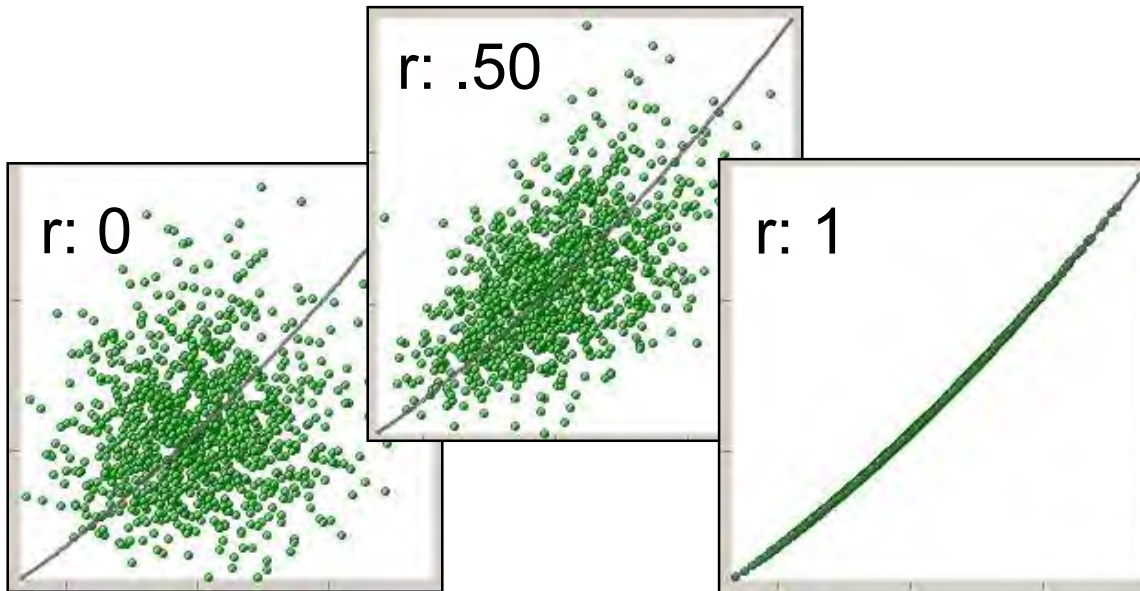


Correlated

*Note shift of **mean**, and increased **variability***

# Quantifying Correlation

- The correlation coefficient 'r' can vary between -1 and +1
- Level of correlation to inject depends if fairly subjective and often can't be proven - program engineers can point you in right direction
- Guidelines:
  - Injecting perfect correlation (+/- 1) is discouraged
  - all elements measured correlation should be at minimum +/- 0.5 (5 elements), .25 (10 elements) or .10 (20 elements)

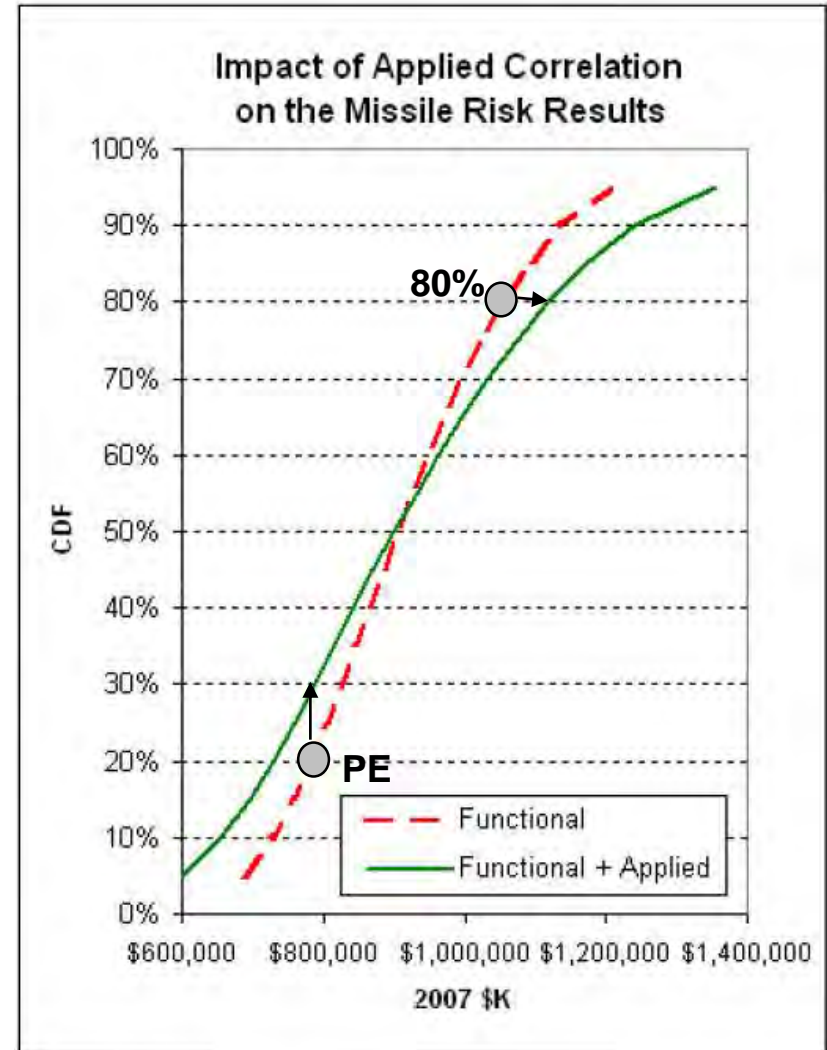


Strength	Positive	Negative
None	0.00	0.00
Weak	0.25	-0.25
Medium	0.50	-0.50
Strong	0.90	-0.90
Perfect	1.00	-1.00

Ref: *Air Force Cost Risk Handbook*

# Effects of Injecting Correlation

- Injecting correlation increases the coefficient of variation
- **Injecting correlation creates a CER between the two cost items and should only be done when one is believed to exist**
- When falsely ignored, ignoring correlation leads to:
  - An incorrect confidence level; lower if PE < 50 %-ile, higher if PE > 50 %-ile
  - An overestimation (for %-iles under 50%) or underestimation (for %-iles over 50%) of costs at all percentiles



Source: Air Force Cost Risk Handbook

# Next Step

1. Develop point estimate ✓
2. Identify the risk areas in the point estimate ✓
3. Determine uncertainty around point estimate ✓
4. Determine discrete risks and opportunities ✓
5. Apply correlation between risks and opportunities ✓
6. Run the simulation
7. Assess the reasonableness of results/check for errors
8. Calculate, allocate and phase risk dollars (if applicable)
9. Tell the risk story - show the results



# Simulations

- Once all of the previously discussed factors have been assessed, it is time to set up the simulation
- There are a variety of COTS tools that have Monte Carlo Capabilities
  - Crystal Ball
  - @Risk
  - ACEIT
  - RealTime Analytics™
- It is also possible to build Monte Carlo simulations in Excel using a few lines of simple VBA code

# Next Step

1. Develop point estimate ✓
2. Identify the risk areas in the point estimate ✓
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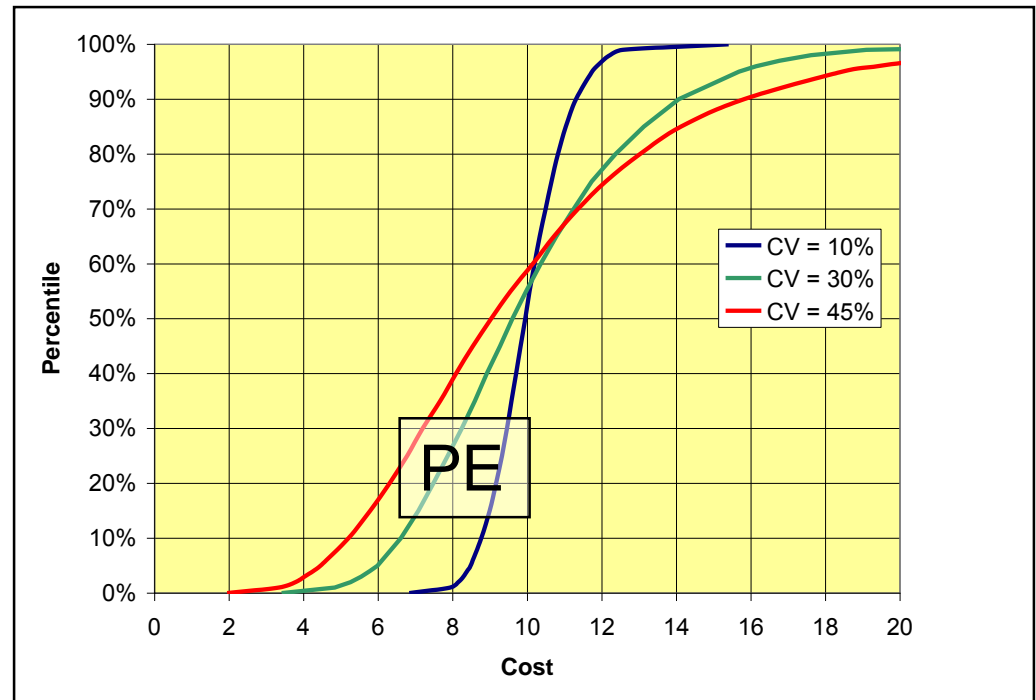
# Interpreting the Results

- The next several slides will walk through interpreting the results of risk analysis

- What is the range of potential costs for this program?
  - Is my estimate too optimistic?
- In order to be confident there will be no cost overrun, at what level do I need to fund this program?
- Given the risks and uncertainty surrounding my cost estimate, how do I spread risk dollars within my WBS?
- How much reserve (or holdback) should I allocate for this program?
- What is my optimal risk mitigation strategy?
- Given a set of alternatives, what is my optimal solution?

# Assess Reasonableness

- As with any analysis, the results should be reviewed for reasonableness
- Check the CV at various levels (Total Program, R&D, Production, etc)
  - 35-45% High Risk Program
  - 25-35% Medium Risk Program
  - 10-20% Low Risk Program
- Be sure to understand why the point estimate is at the confidence level it is at
- The risk dollars between the mean and PE should be in the same ballpark as historical cost growth of analogous programs



# Next Step

1. Develop point estimate ✓
2. Identify the risk areas in the point estimate ✓
3. Determine uncertainty around point estimate ✓
4. Determine discrete risks and opportunities ✓
5. Apply correlation between risks and opportunities ✓
6. Run the simulation ✓
7. Assess the reasonableness of results/check for errors ✓
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# Allocating Risk Dollars

- To understand why there are complicated techniques to allocate risk dollars, it is best to begin by talking about ways allocation can be done incorrectly
  1. Allocating risk dollars by the proportion of total cost that each WBS represents
    - Issue: Just because a WBS has a large proportion of the cost does not mean it is risky
    - Allocating dollars to WBS based on size will most likely short-change high-risk WBSs
  2. Allocating risk dollars by picking the desired confidence level from each WBS' s S-Curve
    - Issue: Percentiles don' t add
    - For example, if each WBS is budgeted at the 80<sup>th</sup> percentile, the whole program may be budget at the 99<sup>th</sup> percentile - Why is this the case?

# Allocating / Phasing

- General steps for allocating risk dollars back to WBS levels are:
  1. Determine the total program cost at the desired percentile
  2. Find the percentile at which, when each WBS is budgeted at that percentile, the desired total program cost is achieved
    - For example:
      - The 80<sup>th</sup> percentile of cost for Program X is \$100
      - When each WBS is budgeted at the 65<sup>th</sup> percentile, the desired total cost of \$100 is achieved
- There are several ways to time phase risk dollars, none of which has been proven to be a “best practice”
  - Spread risk dollars using a back-loaded beta curve
  - Spread risk dollars using same spread as current budget
  - Spread risk dollars based on time frames that risks are expected to occur during, or that risks have been experienced in the past

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# Summary of Risk Analysis Methodologies



# 1. Inputs-Based Simulation Method

- Inputs-based simulation method provides decision makers with the most information about their program's cost risk and uncertainty
- The data and analysis required to reach this level of detail also mean that this method is the most time consuming of the three described in this module
- The time required to produce this analysis can be greatly reduced if the risk analysis effort is combined with the cost estimating and risk analysis efforts
  - Combining with the cost estimating effort also ensures that risk and uncertainty are correctly captured

## 2. Outputs-Based Simulation

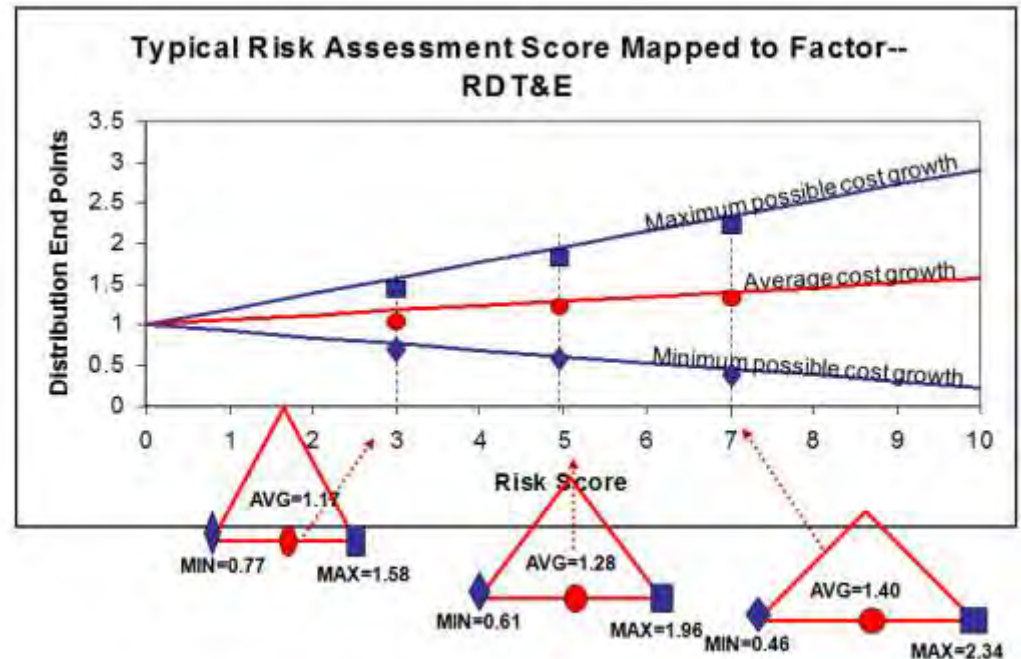
- An alternative method to inputs-based simulation is the outputs-based simulation method
- The outputs-based method differs from the inputs-based method in that, you guessed it, uncertainty is applied only to the cost outputs
- The two main decisions in performing outputs-based simulation analysis are:
  - The level at which to apply the risk/uncertainty distributions
  - The method by which to choose the risk/uncertainty distributions
- Outputs based simulation is best used early in a program's lifecycle when data is sparse and requirements are fluid

# Outputs-Based Simulation

- Risk/uncertainty distributions can be applied in many different ways
  - Commodity cost growth distributions
    - Only applicable at the top level
    - Can not be parsed out to the WBS level!
      - This was one of the points specifically called out in the GAO's decision to overturn the Air Force's Tanker decision
  - Subject matter based uncertainty distribution
    - Can be applied at any level of the estimate
    - Don't forget to increase the uncertainty as applicable
  - Cost growth distributions generated from risk scoring matrices
    - Hardware and software are scored and those scores are mapped to distributions applied to the appropriate WBS items

# Scoring & Mapping of Risks

Risk Categories	Risk Scores (0=Low, 5=Medium, 10=High)				
	0	1-2	3-5	6-8	9-10
1 Technology Advancement	Completed (State of the Art)	Minimum Advancement Required	Modest Advancement Required	Significant Advancement Required	New Technology
2 Engineering Development	Completed (Fully Tested)	Prototype	HW/SW Development	Detailed Design	Concept Defined
3 Reliability	Historically High for Same Item	Historically High on Similar Items	Known Modest Problems	Known Serious Problems	Unknown
4 Producibility	Production & Yield Shown on Same Item	Production & Yield Shown on Similar Items	Production Yield Feasible		
5 Alternate Item	Exists or Availability on Other Items Not Important	Exists or Availability of Other Items Somewhat Important	Potential Alternative U Developme		
6 Schedule	Easily Achievable	Achievable	Somewhat Challengin		



Unit III - Module 9

# 3. Scenario Based Method

- Method was developed as an alternative to simulation based methods
- The general steps are as follows:
  1. Develop a protect scenario
    - The protect scenario represents a grouping of major risks that the program manager would like to manage and budget for
  2. Determine the reserve dollars needed to cover the risks included in the protect scenario
- “Statistics” can be applied to the methodology by adding the following, optional steps
  1. Estimate the confidence level of the point estimate
    - Derived using subject matter expert judgment
  2. Estimate the CV of the estimate
    - Either subjective or historically based
  3. Model the probabilistic cost estimate using a lognormal distribution
  4. Find the confidence level of the protect scenario
  5. Determine if additional funding is needed to reach a desired confidence level

# Scenario Based Method Conclusions

- The Scenario Based Risk Methodology is an invaluable tool for program managers
  - The protect scenario provides a tangible outcome that can be managed and guarded against
- However, its use as a cost risk analysis technique is highly suspect
  - Does not protect against unknown-unknown risks
  - Uses subjective measures of:
    - Confidence level of the point estimate
    - CV of the estimate
    - Distribution of the estimate
  - If entire methodologies are needed to assess these measures, what leads us to believe that we can estimate them subjectively?

# The Risk Cube Method

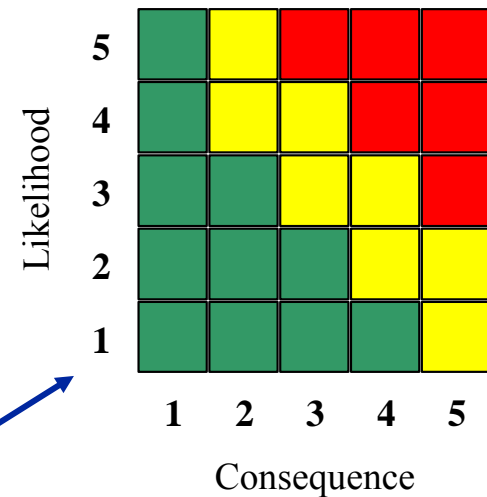
## Likelihood

Level	Likelihood
1	Not Likely
2	Low Likelihood
3	Likely
4	Highly Likely
5	Near Certainty

## Consequence

Level	Technical	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor technical shortfall	Slip < <u>  </u> month(s)	< (1% of Budget)
3	Moderate technical shortfall	Slip < <u>  </u> month(s) of critical path. Sub-system slip > <u>  </u> month(s).	< (5% of Budget)
4	Unacceptable, workarounds available	Slip < <u>  </u> months	< (10% of Budget)
5	Unacceptable, no alternative exist	Cannot achieve key program milestones	> (10% of Budget)

**Note: Generic Risk Cube**



**Risk Item Assessments:**

Category	Level	Likelihood	Consequence
Statement			
Cause			
Mitigation			

# Pros and Cons of the Risk Cube

- The Risk Cube relies on:
  - Complete lists of what could happen
  - Accurate Pf' s and Cf' s
  - Mapping of risk items to the WBS
- Pros:
  - Intuitive and Engineer/Designer-oriented outcome
  - Amenable to mitigation - specific
- Cons:
  - Almost always understates risk because:
    - Identification and scoring by SMEs makes bias (low!) likely
    - Enumeration of “all the things that can go wrong” will inevitably leave out unknown unknowns
    - Aggregate values of trivial, unlisted risks is often bigger than even the largest listed risk



# Summary of Methodologies

Methodology	Pros	Cons
Inputs-Based Simulation	<p>Provides decision makers with, by far, the most insight into what is driving cost risk and uncertainty</p> <p>Once the model is built, it can be quickly updated: low recurring cost to perform analysis</p> <p>Relies on statistics and is the most objective of all three methods</p> <p>Because performed at a lower level, is easiest to integrate with the IMS to perform schedule risk analysis</p>	<p>The most difficult analysis to perform. Easy to do wrong and errors are difficult to find</p> <p>Requires data and sophisticated data analysis - High fixed cost to performing analysis</p> <p>Can miss unknown-unknown risks</p> <p>Difficult to mesh probabilistic results with a deterministic world (example: allocating \$'s to WBS items)</p>
Outputs-Based Simulation	<p>Is still a statistical method, just generally at a higher level</p> <p>Applying historical, top level cost growth distributions captures unknown-unknown risks</p>	<p>Choice of uncertainty distributions is subjective and will always be questioned</p> <p>Difficult to mesh probabilistic results with a deterministic world (example: allocating \$'s to WBS items)</p> <p>Provides less insight into what is driving risk and uncertainty</p>
Scenario Based Method	<p>Quickest turn-around time</p> <p>The protect scenario is invaluable for program managers and provides a tangible and actionable set of risks to guard against</p>	<p>Misses unknown-unknowns</p> <p>Confidence level of point estimate, CV of estimate and choice of uncertainty distribution are all subjective. If the other two methodologies are entirely centered around finding these three measures, and we have studies showing that SME's tend to underestimate uncertainty, what leads us to believe that we can accurately estimate them correctly?</p>

- The above table assumes the analysis is performed correctly, it does not account for analyst errors

# Conclusion

- We hope that this module has given you a satisfactory introduction to various risk analysis methodologies
- If you have any additional questions, or would like to discuss implementing these techniques on your program, contact:
  - Eric Druker
    - [Druker Eric@bah.com](mailto:Druker_Eric@bah.com), (314) 368-5850
  - Greg Hogan
    - [Gregory.Hogan@pentagon.af.mil](mailto:Gregory.Hogan@pentagon.af.mil), (703) 609-9134
- The most important takeaway from this module is that risk analysis is most often about gleaning all possible information from available data
- The two most common errors in risk analysis are:
  - Not fully utilizing the information that lies within the data
    - Or similarly, not using the data at all because it does not appear useful
  - Modeling risk and uncertainty using the incorrect distribution
    - Almost always leads to an underestimation of both risk and uncertainty

# Correlation in Risk Models

- In risk analysis, correlations are critical to successful simulations used to find distributions of cost
  - Correlations are thought to be widely present among elements of cost, but little data exists to determine them
  - Without accounting for correlation, summing multiple independent risk distributions will lead to an artificial degradation in the CV
    - This is known as the “Square Root of N” problem - *see next slide*
- Lacking discernable correlations, risk analysts are forced to rely on Subject Matter Experts to estimate correlations
  - These correlations are subtle and difficult to estimate
  - Estimated correlations, to be usable, must be “coherent”, as discussed later
- Once the desired correlation between all cost elements is determined, the next problem is to build these correlations into the risk model
- The following slides will present a quick method for inducing Pearson’s correlation between input random variables while preserving their marginal distributions

# Risk Resources - Books / Web

- *Against the Gods: The Remarkable Story of Risk*, Peter L. Bernstein, August 31, 1998, John Wiley & Sons
- *Living Dangerously! Navigating the Risks of Everyday Life*, John F. Ross, 1999, Perseus Publishing
- *Probability Methods for Cost Uncertainty Analysis: A Systems Engineering Perspective*, Paul Garvey, 2000, Marcel Dekker
- *Introduction to Simulation and Risk Analysis*, James R. Evan, David Louis Olson, James R. Evans, 1998, Prentice Hall
- *Risk Analysis: A Quantitative Guide*, David Vose, 2000, John Wiley & Sons
- Decisioneering - Makers of Crystal Ball for Monte Carlo simulation  
<http://www.decisioneering.com>
- Palisade - Makers of @Risk for Monte Carlo simulation  
<http://www.palisade.com>

# Risk Resources - Papers

- *Approximating the Probability Distribution of Total System Cost*, Paul Garvey, DoDCAS 1999
- *Why Cost Analysts should use Pearson Correlation, rather than Rank Correlation*, Paul Garvey, DoDCAS 1999
- *Why Correlation Matters in Cost Estimating*, Stephen Book, DoDCAS 1999
- *General-Error Regression in Deriving Cost-Estimating Relationships*, Stephen A. Book and Mr. Philip H. Young, DoDCAS 1998
- *Specifying Probability Distributions From Partial Information on their Ranges of Values*, Paul R. Garvey, DoDCAS 1998
- *Don't Sum EVM WBS Element Estimates at Completion*, Stephen Book, Joint ISPA/SCEA 2001
- *Only Numbers in the Interval -1.0000 to +0.9314... Can Be Values of the Correlation Between Oppositely-Skewed Right-Triangular Distributions*, Stephen Book, Joint ISPA/SCEA 1999
- *An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis*, R. L. Coleman, S. S. Gupta, DoDCAS, 1994
- *Weapon System Cost Growth As a Function of Maturity*, K. J. Allison, R. L. Coleman, DoDCAS 1996
- *Cost Risk Estimates Incorporating Functional Correlation, Acquisition Phase Relationships, and Realized Risk*, R. L. Coleman, S. S. Gupta, J. R. Summerville, G. E. Hartigan, SCEA National Conference, 1997

# Risk Resources - Papers

- *Cost Risk Analysis of the Ballistic Missile Defense (BMD) System, An Overview of New Initiatives Included in the BMDO Risk Methodology*, R. L. Coleman, J. R. Summerville, D. M. Snead, S. S. Gupta, G. E. Hartigan, N. L. St. Louis, DoDCAS, 1998 (**Outstanding Contributed Paper**) and ISPA/SCEA International Conference, 1998
- *Risk Analysis of a Major Government Information Production System, Expert-Opinion-Based Software Cost Risk Analysis Methodology*, N. L. St. Louis, F. K. Blackburn, R. L. Coleman, DoDCAS, 1998 (**Outstanding Contributed Paper**), and ISPA/SCEA International Conference, 1998 (**Overall Best Paper Award**)
- *Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution*, J. R. Summerville, H. F. Chelson, R. L. Coleman, D. M. Snead, Joint ISPA/SCEA International Conference 1999
- *Risk in Cost Estimating - General Introduction & The BMDO Approach*, R. L. Coleman, J. R. Summerville, M. DuBois, B. Myers, DoDCAS, 2000
- *Cost Risk in Operations and Support Estimates*, J. R. Summerville, R. L. Coleman, M. E. Dameron, SCEA National Conference, 2000

# Risk Resources - Papers

- *Cost Risk in a System of Systems*, R.L. Coleman, J.R. Summerville, V. Reisenleiter, D. M. Snead, M. E. Dameron, J. A. Mentecki, L. M. Naef, SCEA National Conference, 2000
- *NAVAIR Cost Growth Study: A Cohorted Study of the Effects of Era, Size, Acquisition Phase, Phase Correlation and Cost Drivers*, R. L. Coleman, J. R. Summerville, M. E. Dameron, C. L. Pullen, D. M. Snead, ISPA/SCEA Joint International Conference, 2001
- *Probability Distributions of Work Breakdown Structures*, R. L. Coleman, J. R. Summerville, M. E. Dameron, N. L. St. Louis, ISPA/SCEA Joint International Conference, 2001
- *Relational Correlation: What to do when Functional Correlation is Impossible*, R. L. Coleman, J. R. Summerville, M. E. Dameron, C. L. Pullen, S. S. Gupta, ISPA/SCEA Joint International Conference, 2001
- *The Relationship Between Cost Growth and Schedule Growth*, R. L. Coleman, J. R. Summerville, DoDCAS, 2002
- *The Manual for Intelligence Community CAIG Independent Cost Risk Estimates*, R. L. Coleman, J. R. Summerville, S. S. Gupta, DoDCAS, 2002